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Effects of Bird Activity, Ventilation Rate and Humidity on PM_{10} Concentration and Emission Rate of a Turkey Barn

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Abstract. *Concentrations and emissions of particulate matter with aerodynamic diameters ≤ 10 μm (PM_{10}) were continuously measured in a mechanically ventilated turkey grow-out barn in central Iowa. The PM concentrations were measured with Tapered Element Oscillating Microbalance (TEOM) units; and ventilation rate (VR) of the barn was measured by monitoring the runtime of calibrated ventilation fans. Bird activity (BA) was monitored with passive infrared detectors (PIDs). This paper describes the effects of BA, VR and indoor relative humidity (RH) on the PM concentration and emission rate (ER) based on 18 days of full 24-hr dynamic data collected during 67 days of flock-growing period (bird age of 40 - 107 d) in wintertime. Considerable diurnal variations were observed in BA, PM concentration and PM ER of the turkey barn. The PM concentration and ER were positively related to BA but negatively related to indoor RH. VR was negatively related to PM concentration but positively related to ER. The PM_{10} ER during the monitoring period varied from 2.71 to 25.6 mg/hr·bird or 13.4 to 28.8 g/d·AU (AU = 500 kg body mass).*

Keywords. *Particulate matter, Air emissions, Turkey activity, TEOM, Animal unit (AU).*

Introduction

Particulate matter (PM) creates ambient air quality concerns when they are released to the atmosphere. PM is one of the most prominent air pollutants associated with animal feeding operations (AFOs). To control animal-exposure PM level and emissions from the emitting sources, it is important to understand and characterize the factors that influence the PM generation and emission. These factors include, but not limited to, indoor climatic conditions, building ventilation rate, heating and cooling schemes, animal type and age, feed type and feeding schemes, litter or manure conditions, and lighting programs. In mechanically ventilated facilities, high ventilation rate (VR) in summer results in lower indoor PM concentration due to more air dilution but may increase PM emission rate (Takai et al., 1998; Haeussermann et al., 2008). Animal activity is the predominant factor that influences airborne particle concentrations (Dawson, 1990; Pedersen et al, 1995; Perkins et al, 1997). However, there were few studies that actually characterize or quantify the impact of animal activity on PM concentrations and emissions (Perkins et al., 1997; Haeussermann et al., 2008). In fact, the presumed relationship between animal activity and PM concentrations is often based on general impressions and subjective evaluation of animal behavior and activity. Several techniques are used to quantify animal activities, such as video recording and digital image analysis of the video records, infrared (IR) transmitter/receiver system, and passive IR motion detectors (PIDs). An activity sensing system has been developed for measuring total activities in a group of animal (Pedersen et al., 1995). However, information is meager concerning animal activity and its impact on PM concentrations in poultry operations.

The objective of this study was to delineate the effects of bird activities (BA), ventilation rate (VR), and indoor relative humidity (RH) on PM_{10} (particulate matter with aerodynamic diameters ≤ 10 μm) concentration and emission rate (ER) of a commercial grow-out turkey barn.

Materials and Methods

The Monitored Commercial Turkey House and Flock Information

A commercial turkey grow-out house located in central Iowa was continuously monitored for ammonia (NH_3) and particulate matter (PM) emissions for one year (May 2007– April 2008). The curtain-sidewall turkey house originally used primarily natural ventilation (NV) via operation of the south sidewall curtains and sliding doors on the north sidewall. To accommodate the air emissions monitoring study, the east end (about 40%) of the barn was converted from mostly natural ventilation to a totally mechanically ventilated (MV) room (60 × 335 ft). The MV room used cross ventilation in cold weather and tunnel ventilation in mild/warm weather (Figure 1). The MV room had five 60-cm (24-in) diameter sidewall exhaust fans spaced about 18.3 m (60 ft) apart, used to provide cold weather ventilation. In addition, one 123-cm (48-in) and six 132-cm (52-in) tunnel fans were used to provide warm/hot weather ventilation, at a maximum VR of 50 m^3/hr·bird (30 CFM/bird).

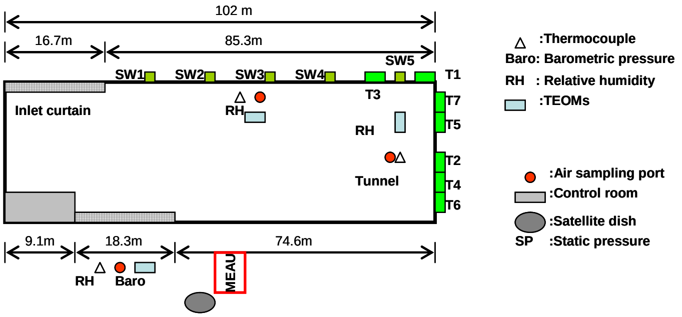

Figure 1. Schematic layout of the turkey grow-out house monitored in this study.

Generally, tom turkeys at 5 weeks of age were moved from the brooder barn to this grow-out barn, where they were raised till market age of 20-21 wk. Caked litter was removed after each flock and fresh bedding (oat hull) added before placement of the next flock. The birds had free access to feed and water. For the flock analyzed in this paper, 38-day-old tom turkeys (on January 7, 2008) were moved from the brooder barn to the grow-out room. While the flock was continuously monitored for the air emission study, 18 days worth of full 24-hr data of PM concentration, PM ER and BA, covering 67 days of the flock growth period (Table 1), were used to evaluate the effects of BA, VR and RH on PM concentration and ER.

Table 1. Test days with full 24-hr response data

Start	End
1/09/08 0:00	1/11/08 23:59
1/20/08 0:00	1/22/08 23:59
1/31/08 0:00	2/02/08 23:59
2/13/08 0:00	2/15/08 23:59
3/04/08 0:00	3/06/08 23:59
3/15/08 0:00	3/16/08 23:59

Monitoring System

To achieve high-quality data on the magnitude and dynamics of PM_{10} emissions from the turkey barn, an accurate and responsive measurement system was essential. To this end, Tapered Element Oscillating Microbalance (TEOM) (Model 1400a, Thermo Fisher Scientific, Waltham, MA) monitors were used along with measurement of instantaneous building VR to quantify dynamic PM_{10} concentration and emission. Two PIDs (SRN-2000, Visonic Inc., Bloomfield, CT, USA) were mounted 2 m (6 ft) above the floor: one at the tunnel end and the other in the middle of the house. The PID motion detection sensors were equipped with a #100 lens that had a 90 deg and 18 m radius coverage (Figure 2). The original AC signals from the PIDs were converted to DC signals using full wave rectification. The converted DC signals were then amplified and smoothed for the final processing.

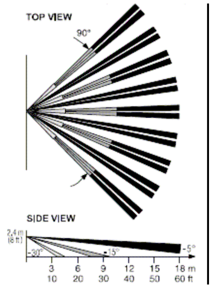

Figure 2. Coverage pattern of the passive IR detection (PID) motion sensor.

The PM_{10} ER of the house or room can be calculated as follows:

$$[ER_{PM}] = \sum_{e=1}^{2}[Q_e]\left([PM]_e - \frac{\rho_e}{\rho_i}[PM]_i\right) \times 10^{-6} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}} \quad (1)$$

where $[ER_{PM}]$ = PM ER of the house (g/hr house)
$[Q_e]$ = VR of the room at field temperature and barometric pressure (m^3/hr house)
$[PM]_i$ = PM concentration of incoming house ventilation air (ug/m^3)
$[PM]_e$ = PM concentration of exhaust house ventilation air of the house (ug/m^3)
T_{std} = standard temperature, 273.15 K
T_a = absolute house temperature, (°C+273.15) K
P_{std} = standard barometric pressure, 101.325 kPa
P_a = atmospheric pressure for the site elevation, kPa
ρ_e = air density of exhaust air, kg dry air / m^3 moist air
ρ_i = air density at incoming air, kg dry air / m^3 moist air

A Mobile Air Emissions Monitoring Unit (MAEMU), as described by Burns et al. (2006), was used in this study. PM_{10} concentration, BA signal, fan operational status, and building static pressure were continuously monitored at 1-s intervals and recorded at 30-s intervals. A data acquisition system (DAQ) program was developed using LabView 7 software (National Instruments, Corporation, Austin, TX) and used in conjunction with the compact Fieldpoint modules for data acquisition and control. Five-min averages of the response variables were used in the statistical analysis.

Results and Discussion

Diurnal Variations in PM_{10} Concentration, Emission Rate (ER), and Bird Activity (BA)

As shown in Figure 3, PM_{10} concentration and ER and BA exhibited distinctive diurnal variations. The BA and PM_{10} ER were much higher during the day than at night, even with artificial lighting at night. The lower BA at night could have been attributed to the less natural light that would be available through the nylon curtains during the day. The PM_{10} concentration had a stronger relationship with VR. Figure 3 shows that the PM_{10} concentration declined under higher VR at 97 d of age but the corresponding PM_{10} ER was elevated, as compared to those at 40 d of age.

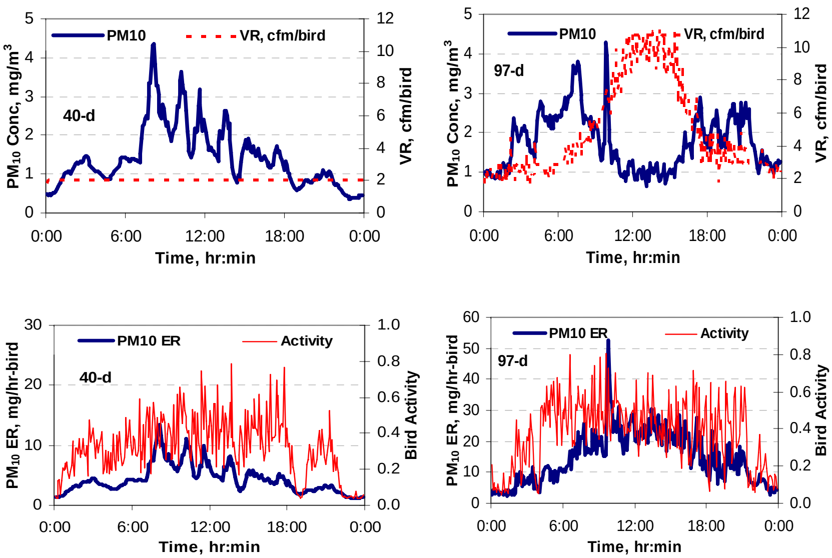

Figure 3. PM_{10} concentration, emission rate, and ventilation rate vs. bird activity for 40-d and 97-d-old turkeys.

Effect of Bird Activity (BA) on PM_{10} Concentration and Emission Rate (ER)

The spikes in PM_{10} concentration and ER were related to BA (Figure 3). In general, higher BA led to elevated PM_{10} concentration and ER. Note that VR can dramatically affect PM_{10} concentration such that PM_{10} concentration decreased with increasing VR even when BA remained quite stable. However, PM_{10} concentration was highly correlated to BA when VR was constant (e.g., 40 d of age, Figure 3). Figure 4 demonstrates a slight linear relationship between BA and PM_{10} ER and concentration, with a R^2 value of 0.138 and 0.154, respectively. As mentioned above, PM_{10} ER and concentration could also be influenced by other variables, such as VR, RH, amount and condition of litter, and bird size. To evaluate the relationship between the numerous input variables and PM_{10} concentration or ER, a multiple linear regression analysis was performed, of the form,

$$Y= \beta_0+ \beta_1X_1+ \beta_2X_2+ \beta_3X_3+ \beta_4X_4 \qquad [2]$$

where Y = PM_{10} concentration (mg/m^3) or PM_{10} ER (mg/hr-bird)
X_i = influencing variables
β_i = regression coefficient

Variability in PM_{10} ER was mainly affected by BA, VR, and RH (R^2=0.76, Table 2). In contrast, the main affecting factors for PM_{10} concentration were BA, VR, indoor temperature, and bird age (R^2=0.26, Table 3). Bird activity positively impacts both PM_{10} ER and concentration as higher BA stimulates more PM generation from the litter. VR affected PM_{10} ER and concentration differently in that higher VR reduced PM concentration (due to greater dilution) but increased PM emission. Elevated RH led to less PM generation and thus lower emission to the environment. The PM_{10} emission increased with bird age or higher indoor temperature (presumably from birds and drier litter).

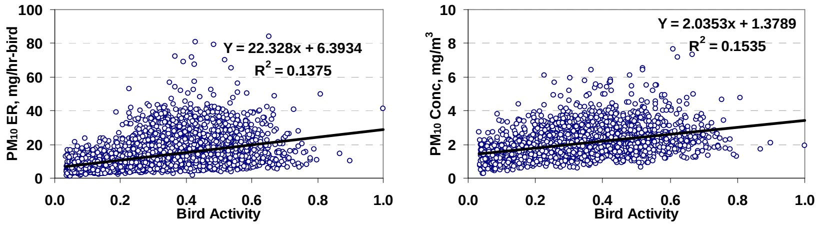

Figure 4. Relationship of PM10 emission rate and concentration to bird activity of a turkey barn.

Table 2. Multiple linear regression of PM_{10} emission rate vs. influencing variables (R^2=0.76)

Variables	Coefficients		P values
	β	SE	
Intercept	-4.64	0.88	<0.0001
BA (0~1)	10.1	0.40	<0.0001
VR, cfm/bird	4.73	0.04	0
RH, %	-4.40	1.63	0.0069

BA = bird activity; VR = building ventilation rate; RH = relative humidity

Table 3. Multiple linear regression of PM_{10} concentration vs. Influencing variables (R^2=0.26).

Variables	Coefficients		P values
	β	SE	
Intercept	-1.30	0.17	<0.0001
BA (0~1)	2.25	0.062	<0.0001
VR, cfm/bird	-0.110	0.009	<0.0001
Air temp, °C	0.068	0.0065	<0.0001
Bird age, day	0.020	0.0008	<0.0001

BA = bird activity; VR = building ventilation rate

The daily PM_{10} data were summarized for the 18-d period, covering about 67-d growth period (bird age of 40 - 107 d) of the flock in wintertime (Table 4). The PM_{10} ER varied from 2.71 to 25.6 mg/hr-bird (13.4 to 28.8 g/d-AU, where AU = animal unit, 500 kg live body mass). Compared to the large variation of PM_{10} ER, PM_{10} concentration and BA had much smaller fluctuations. No significant relationship was observed between BA and PM_{10} concentration or ER in terms of the daily mean values.

Table 4. Daily means of PM_{10} concentration, emission rate, and bird activity during 18-d measurements of a commercial turkey grow-out barn, covering bird age of 40 - 107 d (1 cfm = 1.699 m^3/hr).

Date	Age	Body Wt, kg	Activity	ER, mg/hr-bird	ER, g/ d-AU	Concentration, mg/m^3	VR, cfm/bird	RH, %	T, °C
1/9/08	40	1.72	0.33	4.13	28.8	1.42	1.9	47.5	21.6
1/10/08	41	1.84	0.36	4.06	26.4	1.39	1.9	51.3	22.4
1/11/08	42	1.96	0.42	4.85	29.7	1.68	1.9	51.2	21.3
1/20/08	51	2.89	0.32	3.20	13.4	1.57	1.3	58.1	20.9
1/21/08	52	3.01	0.33	2.71	11.0	1.57	1.3	56.3	20.3
1/22/08	53	3.19	0.36	4.43	16.9	1.71	1.6	53.6	20.9
1/31/08	62	4.40	0.33	8.21	22.8	1.82	2.7	54.7	19.2
2/1/08	63	4.61	0.36	8.64	22.9	1.87	3.0	53.1	20.5
2/2/08	64	4.84	0.33	8.93	22.6	1.69	3.2	53.4	20.7
2/13/08	75	6.60	0.30	9.70	18.0	2.62	2.3	54.6	20.8
2/14/08	76	6.73	0.31	9.18	16.8	2.05	2.6	51.1	19.9
2/15/08	77	7.07	0.32	10.7	18.6	2.02	2.8	51.9	19.5
3/4/08	95	10.5	0.31	14.3	16.9	2.86	2.8	44.5	18.3
3/5/08	96	10.5	0.34	11.3	13.4	2.03	3.2	48.0	16.7
3/6/08	97	10.7	0.33	17.2	19.7	1.68	3.6	51.1	18.5
3/14/08	105	12.2	0.32	25.6	26.3	1.81	6.5	52.9	16.2
3/15/08	106	12.4	0.36	22.8	23.1	2.13	5.2	53.2	16.4
3/16/08	107	12.8	0.37	18.4	18.1	1.57	5.5	52.5	16.1

Conclusions

The following conclusions were drawn from this study.

- Diurnal patterns exist in bird activity, PM_{10} emission rate, and PM_{10} concentration in the turkey barn.
- Bird activity positively impacts both PM_{10} emission rate (ER) and concentration. Increased ventilation rate (VR) reduces PM concentration, but increases PM emission. Indoor relative humidity is negatively related to PM concentration and ER.
- During an 18-d monitoring period (bird age of 40 - 107 d) under winter weather conditions in Iowa, PM_{10} ER varied from 2.71 to 25.6 mg/hr-bird or 13.4 to 28.8 g/d-AU.

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